INFLUENCE OF HYDROGEN SUPPLY ON EMISSIVE CHARACTERISTICS OF PIG WITH METAL-HYDRIDE CATHODE

I.N. Sereda, A.F. Tseluyko, D.L. Ryabchikov, I.V. Borgun, M.O. Goncharenko

V.N. Karazin Kharkiv National University, Kharkiv, Ukraine

E-mail: igorsereda@karazin.ua

The experimental studies of the Penning-type charged particle source with metal hydride cathode are presented. In order to determine the mechanisms responsible for the emission of negative particles in the axial direction, the influence of different hydrogen feeding methods were studied. To simulate hydrogen desorption the cathode of special design was applied and to force only hydrogen ion-stimulated desorption the forced cooling metal hydride cathode was used.

PACS: 52.80.Sm

INTRODUCTION

Application of metal-hydrides (MH) based on Zr-V alloys capable of reversibly storing hydrogen isotopes as cathode material in plasma sources is known to have a number of advantages as compared with common supply systems. Hydrogen desorption from MH is caused by both heating of the sample and the current discharge influence. It allows not only to safety store hydrogen and realize the local gas feeding but to also to raise the efficiency of a source due to metal-hydride hydrogen activation [1]. For instance, experiments with Penning-type ion source using MH-cathode revealed an additional (third) regime of the source working in the range where high discharge voltage appears [2]. In this regime, only the ions from the MH-cathode side are kept on in the axial flow, but the electrons were registered on the opposite side. The negative current increased along with the discharge voltage and at some point it exceeded the ion current. It made possible, for instance, to get compensated beam for technological applications. The problem in source designing was the strong dependence of desorbed neutral hydrogen flow on MH-cathode temperature. It made the stabilizing the discharge regime a difficult problem. This paper is devoted to solving the problem of pressure stabilizing and determining the mechanisms responsible for axial electron emission from the discharge for improving the source characteristics.

1. EXPERIMENTAL SETUP

The experimental setup is based on Penning-type discharge cell represented in Fig. 1.

Three types of cathodes were used in the experiment. The first one is the MH-cathode pressed from powder mixture of saturated with hydrogen
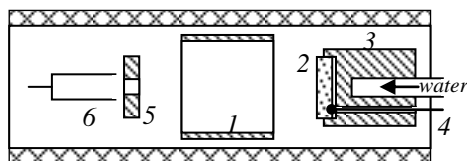
$Zr_{50}V_{50}H_x$ alloy and copper stuff with initial saturation of hydrogen about $900\ cm^3$ under normal conditions was just set in discharge. The second one is the same MH-cathode but with water-cooling. The third one is a copper cathode with hydrogen supply for simulation of hydrogen desorption. All types of cathodes have the same spatial dimensions: 2.0 cm in diameter and 0.5 cm thick. The cathode-reflector is made of copper and has an aperture at the center with 0.5 cm in diameter. In check experiments two solid copper cathodes were used. A collector or an electrostatic energy-analyzer can be set behind the aperture in cathode-reflector.

In hydrogen desorption simulation experiments, balloon let hydrogen in locally through thin holes in the working surface of the copper cathode. The ratio between local (through cathode) and additional (in vacuum chamber) flows of supplied hydrogen as well as intensity of external magnetic field were picked the same as in [2] at third regime of discharge with MH-cathode.

The residual pressure in vacuum chamber did not exceed $5 \cdot 10^{-6}$ Torr. The investigations were carried out at the pressure of $10^{-6} \ldots 10^{-4}$ Torr. A working pressure that is higher that the residual one was achieved by initial balloon hydrogen supply into the vacuum chamber.

2. RESULTS AND DISCUSSION

The typical dependences of collector current on discharge voltage are shown in Fig. 2 for the cases of MH-cathode with water-cooling and without the water-cooling, cathode with supply and solid cathodes (check experiment).
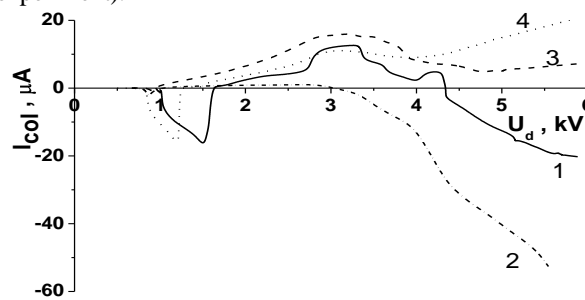

Fig. 2. Dependence of collector current on discharge voltage for different cathodes, $P = 3 \cdot 10^{-5}$ Torr, $H = 1$ kOe: 1 – MH cathode; 2 – water-cooled MH cathode; 3 – simulation experiment; 4 – check experiment

Fig. 1. The scheme of discharge cell:
1 – anode; 2 – MH-cathode; 3 – cathode-holder;
4 – thermocouple; 5 – cathode-reflector; 6 – collector

One can see that the third regime of the source with MH-cathode starts at about 3.0 kV (see lines 1 and 2 in Fig. 2) in both cases: with and without water-cooling. The higher voltages for which the current changes its sign in the case of MH-cathode without cooling are obviously explained by the effect of pressure on ion quantity in the output flow. In simulation experiments, the current on collector diminishes as well (see line 3 in Fig. 2). As it was revealed by retarding field method, there are no electrons in output flow in simulation experiment. (This differs the simulation experiment from the case of MH-cathodes in which current reduction results from the electron part in output ion-electron flow increasing.) So, there is no third regime in simulation experiment as well as in check experiments. This proves the determining role of desorbed hydrogen in producing the axial electron flows at heightened discharge voltages.

Transition to the third regime is followed by step increase of HF-oscillation frequency and amplitude of diocotron type instability [3]. Taking into account a well-known expression for the frequency of diocotron oscillations $f \sim E_r / H$ [4], the raise of oscillation frequency is explained by radial electric field (E_r) increasing caused by redistribution of axial (E_z) and radial (E_r) electric fields in favor of E_r (potential on the axis of the system decreases). Wherein redistribution of radial (E_r) and axial (E_z) electric fields provides the primary ionization in anode layer. Comparison of experiments with MH-cathode and the simulation ones revealed that desorbed hydrogen flow makes an impact on spatial distribution of axial electric field (E_z) in the gap and gradient of E_z arising [3]. Simulation experiments lead to E_z gradient appearance only.

So, the deciding factor for axial electron flow emission is the HF-instability developing under the conditions of hydrogen desorption from MH-cathode in non-equilibrium state. Electron emission only from one side is caused by additional neutral hydrogen flow from the direction of a cathode. At total hydrogen outlet from MH-cathode the third regime disappears, and discharge behaves as in case of usual cathodes.

But the problem with designing a working source is the strong dependence of desorbed hydrogen flow on MH-cathode temperature that makes it difficult to stabilize the discharge regime. From this point of view MH-cathode cooling could solve the problem. This could allow stabilizing the discharge working pressure and eliminating the hydrogen kick caused by uncontrolled thermal decomposition of hydride phases [5]. Low temperature of MH-cathode (lower than hydride phases decomposition one) ensures hydrogen desorption only due to ion-stimulated processes. This provides the possibility to control the hydrogen desorption rate by current discharge and work only on hydrogen desorbed from the cathode. This will reduce the hydrogen consumption and rise the source life time. Further experiments should be carried out to make sure of discharge characteristics not changing.

The typical collector currents are presented in Fig. 3 for the case in which the discharge works only on the hydrogen desorbed from MH-cathode. One can see that the discharge behaves in the same way as in previous
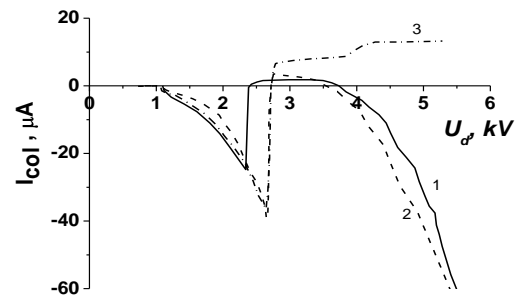

Fig. 3. Dependence of collectors current on discharge voltage for different cathodes, $P = 5 \cdot 10^{-6}$ Torr, $H = 1$ kOe: 1 – MH cathode; 2 – water-cooled MH cathode; 3 – check experiment

experiments with the MH-cathode with an additional external hydrogen supply into vacuum chamber (see lines 1 and 2 in Fig. 2). Moreover, pressure increase does not sufficiently shift the voltage for the discharge transition to the third regime. All these issues give an opportunity to work only on hydrogen desorbed from MH-cathode without external feeding and apply the data obtained in previous experiments. MH-cathode water-cooling is only the tool for pressure maintaining here [4].

Fig. 4 shows ion energy distribution function (IEDF) for all cathodes used in the experiments and for both cases of hydrogen supply: due to desorption from MH-cathode only and with addition external hydrogen supply into vacuum chamber.

Discharge voltages for measuring the IEDF were chosen in the following way. Figures for $U_d = 2.5$ kV correspond to the second discharge regime, when only ions are registered in axial direction [2]. Figures for $U_d = 3$ kV correspond to the transition to third regime (electrons start to appear in the output flow). And figures for $U_d = 3.5$ kV correspond to the third regime of discharge working (output axial current has negative sign). Note that under residual pressure of $P = 5 \cdot 10^{-6}$ Torr there is no data to compare with. That is why only data for MH-cathodes is presented on upper figures in Fig. 4.

One can see qualitatively the same behavior of distribution function in check and simulation experiments (see lines 1 and 2 respectively in Fig. 4). The only difference is the particles quantity output from the discharge. In the case of MH-cathode the distribution function shifts and widens towards the lower values of energy at discharge transition to the third regime. This is due to widening of intensive ionization field from anode layer to discharge axis with lower values of space potential. This phenomenon is the mostly pronounced in the case of MH-cathode without water-cooling (see line 3 in Fig. 4). In This case intensive hydrogen desorption in non-equilibrium state takes place under the influence of discharge current that leads to ionization intensification near the axis. In the case of hydrogen desorption only due to ion-stimulated processes (see line 4 in Fig. 4) the situation is the same but the quantity of desorbed hydrogen is sufficiently lower and, accordingly, the distribution function widens not so much. Data differences (see line 2 in Fig. 4) for simulation experiments are explained by the ratio between local and additional feeding of hydrogen that was maintained to be the same in a whole range of
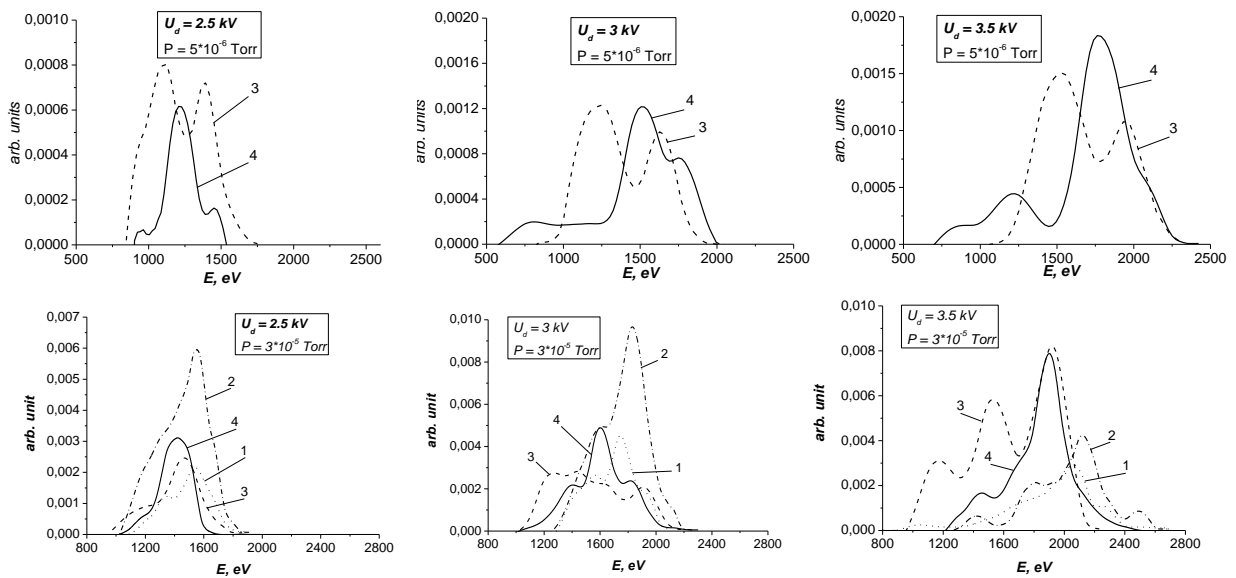
Fig. 4. Ion energy distribution function at H = 1 kOe for different pressures discharge voltages and cathode type: 1 – check experiment; 2 – simulation experiment; 3 – MH-cathode; 4 – water-cooled MH-cathode

discharge voltages. Whereas desorbed hydrogen flow depends on discharge current and for given cases the flow was sufficiently lower than for simulation experiment.

CONCLUSIONS

The possibility of discharge working only on the hydrogen desorbed from MH-cathode due to ion-stimulated processes is shown. The hydrogen desorption does not sufficiently influence the discharge emissive characteristics, which gives an opportunity to use the data obtained in previous experiments.

The deciding factor for axial electron flow emission is HF-instability developing under the conditions of hydrogen being in non-equilibrium state desorption from MH-cathode. Electron output only from one side is caused by additional neutral hydrogen flow from a cathode direction. After hydrogen desorbs from MH-cathode completely, the third regime disappears, and discharge behaves as in the case of usual cathodes.

REFERENCES

1. Yu.F. Shmal'ko, Ye.V. Klochko, N.V. Lototsky // *Int. J. Hydrogen energy.* 1996, v. 21, p. 1057.
2. Ye.V. Klochko, D.L. Ryabchikov, I.N. Sereda, A.F. Tseluyko // *Probl. of Atomic Sci. and Tech. Series "Plasma Electronics and New Acceleration methods" (7).* 2010, № 4, p. 226.
3. I.V. Borgun, D.L. Ryabchikov, I.N. Sereda, A.F. Tseluyko // *Problems of Atomic Sci. and Tech. Series "Plasma Phys."(83).* 2013, № 1, p. 228.
4. Khauer W. Diocotron // *J. Appl. Phys.* 1966, v. 37, № 2, p. 602.
5. A.V. Agarkov, D.L. Ryabchikov, I.N. Sereda, A.F. Tseluyko // *Problems of Atomic Sci. and Tech. Series "Plasma Electronics and New Acceleration Methods" (86).* 2013, №4, p. 301.

ВЛИЯНИЕ СПОСОБА НАПУСКА ВОДОРОДА НА ЭМИССИОННЫЕ ХАРАКТЕРИСТИКИ РАЗРЯДА ПЕННИНГА С МЕТАЛЛОГИДРИДНЫМ КАТОДОМ

И.Н. Середа, А.Ф. Целуйко, Д.Л. Рябчиков, Е.В. Боргун, М.О. Гончаренко

Представлены результаты экспериментального исследования источника заряженных частиц пеннинговского типа с металлогидридным катодом. С целью определения факторов, ответственных за эмиссию отрицательных частиц в аксиальном направлении, изучено влияние разных способов напуска водорода в ячейку. Для имитации десорбции применены катоды специальной конструкции и ион-стимулированная десорбция водорода за счет принудительного охлаждения металлогидридного катода.

ВПЛИВ СПОСОБУ НАПУСКА ВОДНЮ НА ЕМІСІЙНІ ХАРАКТЕРИСТИКИ РОЗРЯДУ ПЕНІНГА З МЕТАЛОГІДРИДНИМ КАТОДОМ

І.М. Середа, О.Ф. Целуйко, Д.Л. Рябчиков, Є.В. Боргун, М.О. Гончаренко

Представлено результати експериментального дослідження джерела заряджених частинок пенінговського типу з металогідридним катодом. З метою визначення факторів, що відповідають за емісію негативних частинок в аксіальному напрямку, вивчено вплив різних способів напуску водню в проміжок. Для імітації десорбції застосовані катода спеціальної конструкції і іон-стимульована десорбція водню за рахунок примусового охолодження металогідридного катоду.